CHAPTER 18

HEATING CONTROL

The passage of electrical current always creates or generates heat. The heating effect of electric current can be utilised to perform many functions (Chapter 6) provided that the quantity of heat produced can be regulated to prevent overheating. Most electrical heating processes and appliances are controlled so that they operate between maximum and minimum limits of temperature. The failure of the controlling device to operate can cause excessive temperature resulting in severe damage to equipment and eventual fire. Figure 18.1 illustrates what can occur if a domestic iron is left on over a long period.

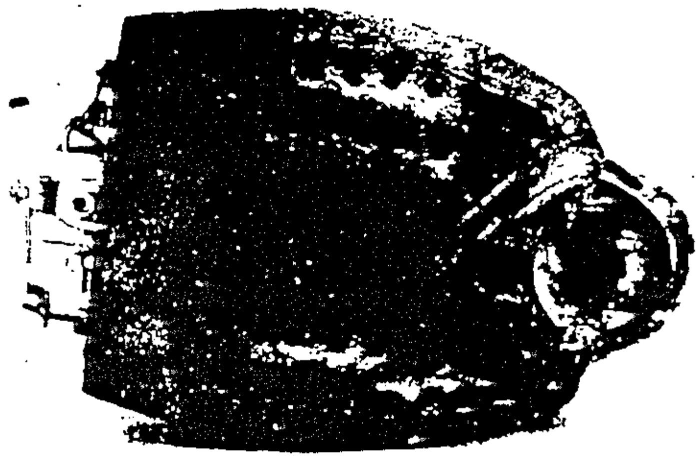


Figure 18.1

Figure 18.2 shows the element of a hot water service whose controlling device failed to operate.

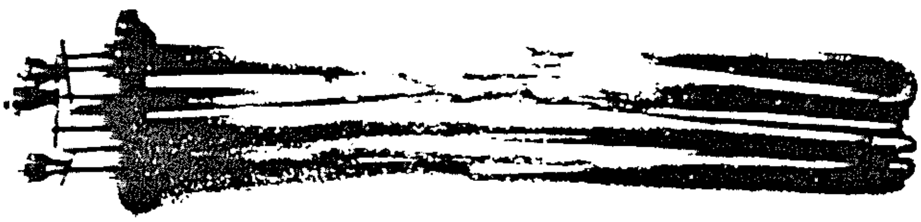


Figure 18.2

From the two photographs can be seen the damage that can be caused if the control device becomes faulty or is deliberately bridged or disconnected from the circuit. There are many methods of heat control but the four most common are:-

(a) three heat switching

(b) thermostates

(c) simmerstats

(d) thermocouples

18.1 THREE HEAT SWITCHING

The three heat system requires two elements and a specially built switch. Figure 18.3 shows the elements used as hotplates in an electric range or in some [illegible]. It also shows the type of switch used to control the heating of these elements.

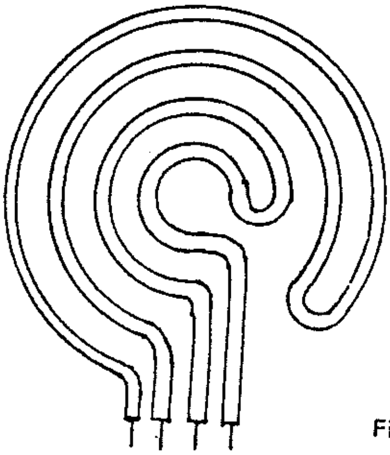


Figure 18.3

The three heating positions of the switch, supply current to the two elements in series (low), the centre element only (medium) and the two elements in parallel (high). The circuit for three heat switching together with the relative internal switch bridges is shown in figure 18.4.

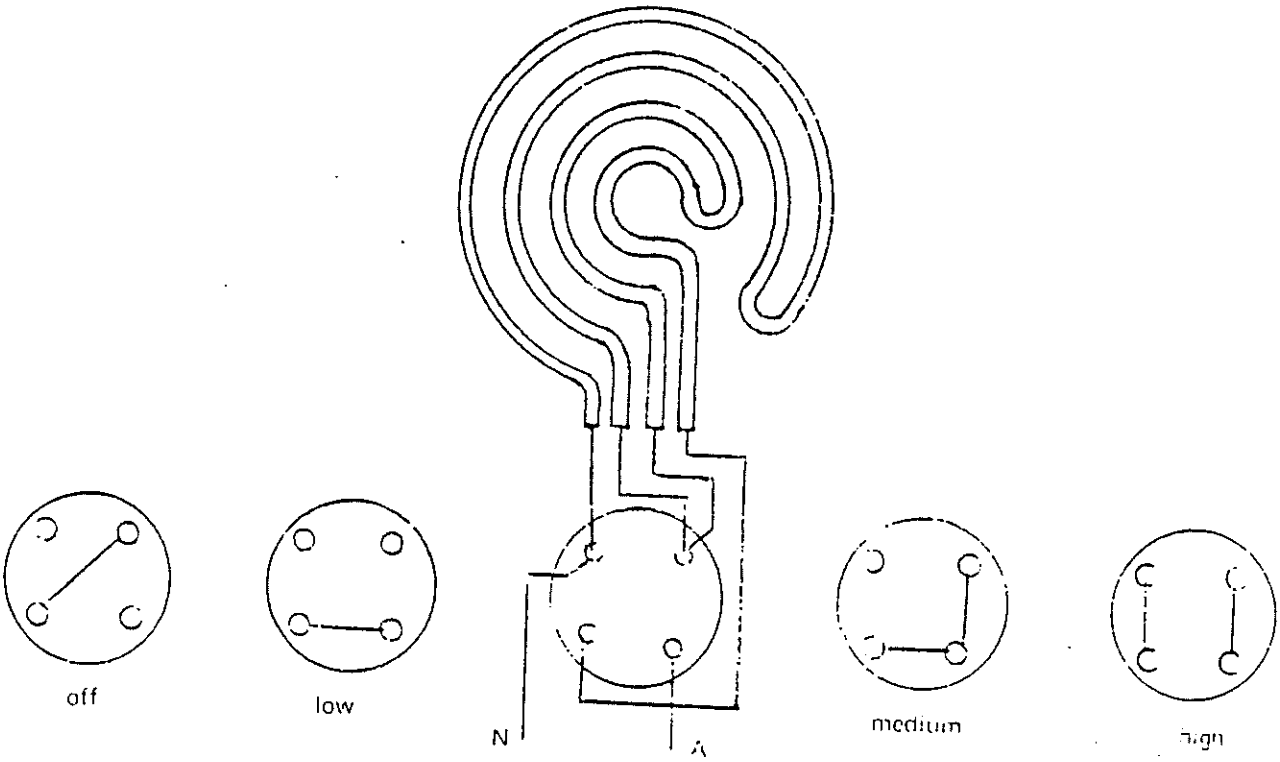


Figure 18.4

The disadvantage of three heat switching is that heat is available in only three definite quantities. The heat generated in the low position is doubled when the switch is moved to the medium position and quadrupled when the switch is in the high position. Three heat switching is used in hot water control and electric blankets.

18.2 LINEAR COEFFICIENT OF EXPANSION

Metals and gases, if free to do so, will change their dimensions with change in temperature. The chemical structure of the material determines the amount by which the dimensions alter for a given temperature change. The amount by which unit quantity of a substance expands when heated through one degree temperature change is called the coefficient of expansion of that substance. In this chapter, the property of the linear coefficient of expansion of metals is used to examine the temperature control of heating devices. Comparisons of the linear coefficient of expansions of different metals is given in Table 18.1.

Table 18.1

SUBSTANCE	COEFFICIENT OF EXPANSION / ^{o}C
Aluminium	22×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Iron	12×10^{-6}
Silver	19×10^{-6}
Zinc	30×10^{-6}

Table 18.1 shows that if identical lengths of iron and zinc were heated through the same temperature range, the length of zinc would increase far greater than the iron. The final length of a piece of material heated through a fixed temperature range can be calculated from the temperature coefficient of expansion equation:-

Let –

a = linear coefficient of expansion / ^{o}C

t_c = change in temperature of the material $(t_f - t_i)$

t_f = final temperature

t_i = initial temperature

Then –

$1 + a$ = change in length per unit due to 1^{o} temperature change

$(1 + at)$ = change in length per unit due to 't' degrees temperature change

Let –

L_c = length of material at initial temperature

L_h = length of material at the final temperature

Then the final length will be the initial length multiplied by the change per unit length.

$$L_h = L_c(1 + at) \text{ units}$$

or

$$L_h = L_c(1 + a(t_f - t_i))$$

Example 18.1

A length of copper bar is 250 mm. long at $20^{o}C$. Calculate its length at $100^{o}C$.

$a = 17 \times 10^{-6} / {}^{o}C$

$t = (100 - 20) = 80^{o}C$

$L_c = 250$ mm

$$L_h = L_c(1 + at)$$

$$= 250(1 + (17 \times 10^{-6} \times 80))$$

$$= 250(1 + 0.00136)$$

$$= 250(1.00136)$$

$$= 250.34 \text{ mm}$$

Example 8.2

A brass bar, 600 mm long increases its length to 600.912 mm when its temperature is increased from 15°C. Calculate its final temperature.

$$L_h = 600.912 \text{ mm}$$

$$L_c = 600 \text{ mm}$$

$$a = 19 \times 10^{-6}$$

$$t_i = 15^{o}C$$

$$t_f = ?\ ^{o}C$$

$$R_h = R_c(1 + (t_f - t_i))$$

$$t_f - t_i = \frac{\frac{R_h}{R_c} - 1}{a}$$

$$= \frac{\frac{600.912}{600} - 1}{19 \times 10^{-6}}$$

$$= \frac{1.00152 - 1}{19 \times 10^{-6}}$$

$$= 80\ ^{o}C$$

$$t_f = 80 + t_i$$

$$= 80 + 15$$

$$= 95\ ^{o}C$$

The difference in rates of expansion of different metals is used to produce bi-metal strip thermostats.

BI-METAL STRIP

If two different types of metal of equal length are welded or fused together a bi-metal strip if formed. The two most common metals used for bi-metal strips are iron and zinc, because of the greater difference in rates of expansion. If this combination of zinc and iron is heated, it will bend due to the zinc increasing its length more than the iron. (Figure 18.5).

Figure 18.5

In heating control, the strip may acquire the necessary heat to bend by its proximity to a heated object or by the passage of current through the strip for a certain time. (Figure 18.6).

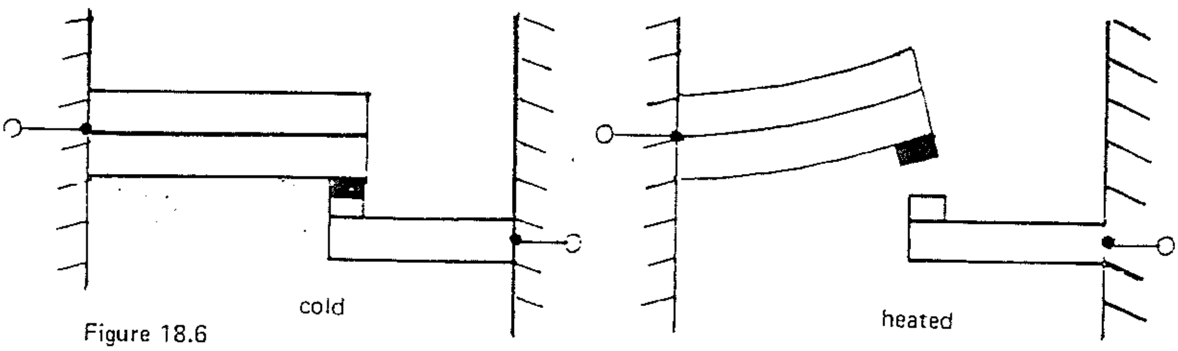


Figure 18.6

18.3 THERMOSTATS

A thermostat is a device which controls temperature. Most thermostats operate due to either the heat developed in a bimetal strip or the expansion and contraction of a gas or liquid.

(a) Bimetal strip thermostats

The bimetal strip thermostat is connected in series with the heating element. The thermostat consists basically of a pair of contacts, one of which is attached to the bimetal strip (figure 18.6). Current drawn by the element passes through the bimetal strip and the contacts causing the bimetal strip to heat up sufficiently to bend and open the contacts. Current in the element and the bimetal strip ceases allowing both to cool or decrease in temperature. As the bimetal strip cools it straightens until the contacts again become closed and the heating process recommences. Bimetal strip thermostats are used in a wide range of heating devices including irons, toasters and other domestic appliances. The bimetal strip thermostat of a demostic iron is shown in figure 18.7.

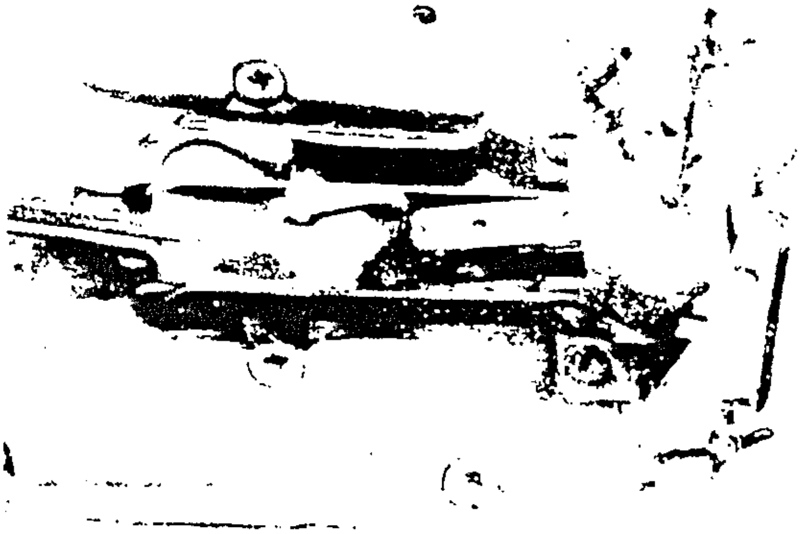


Figure 18.7

Bimetal strip thermostats are also produced in a circular shape. (Figure 18.8).

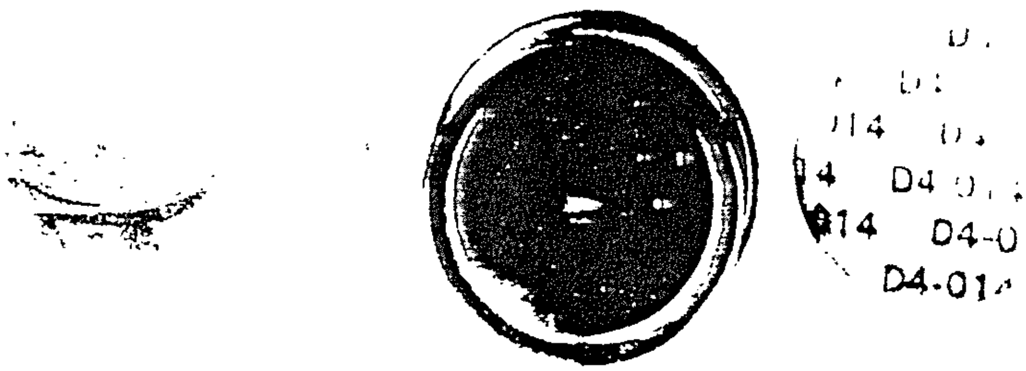
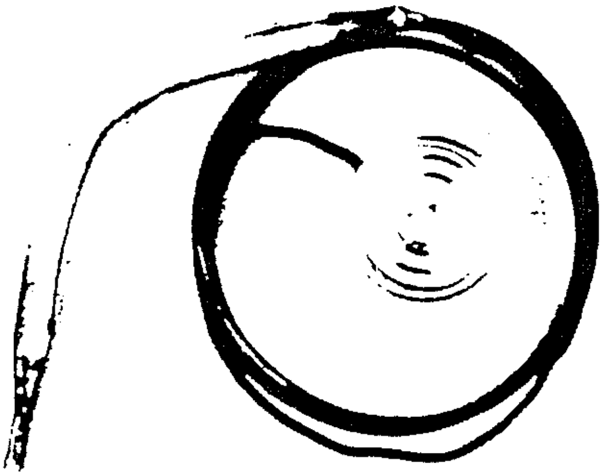


Figure 18.8

Enclosed in the cylindrical bakelite container is a set of normally closed contacts. The bimetal disc rests on top of the container. When the bimetal disk absorbs heat it exerts pressure on a plunger inside the container, opening the contacts. This type of thermostat is used mainly to control the temperature of hot water services. The thermostat is attached to the outer surface of the tank and connected in series with the tank element.

(b) Liquid and vapour pressure thermostats

In bimetal strip thermostats the element current passes through the bimetal strip and the bimetal strip and control device is adjacent or attached to the heated area. Liquid and vapour pressure thermostats are used where the control device is some distance from the controlled area. They are also more accurate than the bimetal strip when a certain temperature is required. Typical applications are refrigerators and the ovens of electric ranges. The thermostat operates due to changes in the pressure of gases or liquids due to temperature changes. The liquid or gas is contained in a long tube (called a capillary tube), or a tube and bulb, which is attached to a set of bellows within the control device. (Figure18.9).



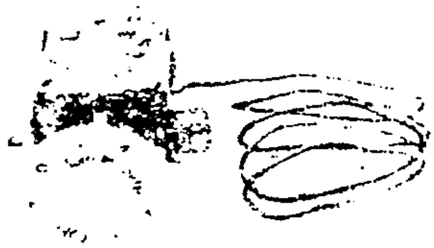


Figure 18.9

The end of the tube or the metal bulb is installed in the area to be regulated. As the temperature of the gas or liquid contained in the section of the themostat in the controlled area changes, the pressure within the bellows changes. The method of controlling the temperature of a refrigerator is shown in figure 18.10. As the temperature of the refrigerator enclosure increases the vapour pressure in the bulb and bellows increases, causing the bellows to expand and close a set of contacts, starting the cooling process.

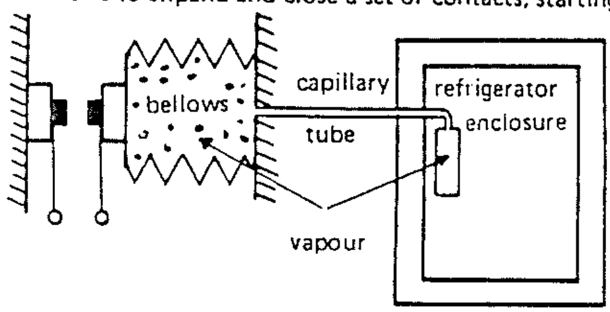


Figure 18.10

As the temperature of the area to be cooled is decreased, the bellows contract, thus opening the contacts and stopping the cooling system.

18.4 SIMMERSTATS

A simmerstat controls the temperature of an element by controlling the amount of power the element consumes. It is still operated by a bimetal strip but the bimetal strip is heated by its own element which is connected in parallel with the heating element. (Figure 18.11).

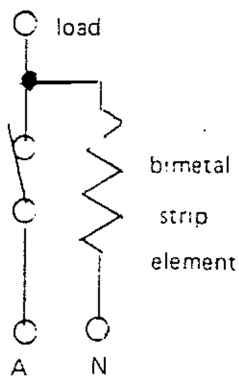
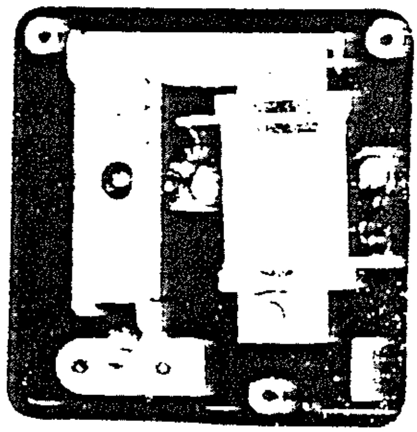


Figure 18.11



When the bimetal switch on the right hand side of the simmerstat is heated by its own element it bends and opens the contacts on the left hand side through a connecting bar at the top of the simmerstat. Simmerstats are used extensively to control the hotplates of electric ranges. They operate on the time it takes the bimetal strip to open the contacts, not the current or temperature of the heating device.

18.5 CONTROL OF TEMPERATURE RANGES

The 'cut in' and 'cut out' points of a thermostat or simmerstat are varied by increasing or decreasing the pressure required to open the thermostats contacts. This pressure is provided by a spring or cam which is connected to an external knob or temperature indicating dial. Turning the temperature selecter to a higher setting increases the pressure on the moveable contact. To open the contact there must be a corresponding increase in temperature change in the heating element. The term used for the range between the 'cut in' and 'cut out' points of a thermostat is known as its **differential** of the thermostat.

18.6 SENSITIVITY

When selecting the device to control the temperature of electrical equipment, care should be taken that the device will operate at the required temperature range, for example a thermocouple is not effective in controlling the temperatures of a refrigerator. The controlling device must be able to sense the required changes in temperature. The sensing ability of the thermostat is known as its sensitivity.

18.7 THE THERMOCOUPLE

In Chapter 3 it was stated that if the junction of two dissimilar metals is heated, while the temperature of the other ends of the junction remains constant, a e.m.f. will be produced. This e.m.f. may be used to control the temperature of heating devices by using the current produced by this e.m.f. to operate control circuit equipment. The e.m.f. produced by a thermocouple depends on the types of material used in the couple and the range of temperature through which the couple is operating. Typical combinations of materials and their operating temperature are -

(i) Copper - constantin 300°C

(ii) Chrome alloy - aluminium alloy 1200°C

The current produced by the e.m.f. of a thermocouple is very small and must be amplified before it can operate the control equipment. Another method of increasing the e.m.f. for control purposes is to connect a number of thermocouples in series. The result, called a thermopile, produces a e.m.f. which is the sum of the e.m.f.'s in each thermocouple. Application of the thermocouple as a thermostat is in the heat control of plastic extruders and electric furnaces.

Equations in this chapter

(1) $L_h = L_c (1 + at)$

(2) $L_h = L_c (1 + a(t_f - t_i))$

TUTORIAL 1.18

(1) The elements of a hotplate controlled by a three heat switch have a resistance of 50 ohms each. If the hotplate is operating from a 240 volt supply calculate the power consumed in the low, medium and high switch positions.

(2) An iron bar 1 m in length is heated in a furnace from 20°C to 200°C. Calculate the length of the bar at its final temperature.

(3) A brass rod has its initial length of 2 m increased by 11 mm when it is heated in a furnace. Calculate the temperature change required to produce this increase.

(4) Determine the coefficient of linear expansion of a piece of material whose origional length of 1.5 meters is increased by 6 mm when it is heated through a range of 200°C.

(5) Calculate the initial length of an aluminium bar that has had its temperature raised 300°C if the final length is 1005 mm.